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THE MOON*

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One Saturday evening, several years ago, I was standing in front of the Lick Observatory with a party of people who had come to look thru the 36-inch telescope. The Sun was just setting behind the hills south of Mt. Tamalpais, and as it disappeared, the slender crescent of the Moon, less than two days past the new, appeared low in the sky south of the sunset point. One of the visitors, after watching it a moment, turned with the question:—"Why is it that the new Moon rises in the west, while the full Moon rises in the east?"

As soon as I recovered, I explained as tactfully as I could that the Moon always rose in the east, but that when it was just past the new Moon stage it rose very near the Sun and after sunrise and therefore could not be seen until the Sun had set, by which time, of course, it was itself approaching the western horizon. But my tact or my explanation, or both, were unequal to the occasion, for when I had finished, the visitor replied with great dignity, "Well! That is the way it may do here, but in Humboldt County the new Moon always rises in the west!"

That any one should be so ignorant concerning the motions of the Moon, is certainly hard to credit; but my visitor differs only in degree from many a famous poet and novelist. I could quote a description of a sunset in a story written by one of the foremost "realist" fiction writers of New England, and published a few years ago in Harper's Monthly Magazine, in which a crescent Moon in the eastern sky adds to the beauty of the scene; or a passage from a novel which was a "best seller" not so very long ago and whose author had a reputation as a scientific man, in which the full Moon rises at midnight. Indeed all kinds of liberties have been taken with the Moon.

Coleridge's lines in *The Ancient Mariner*,

"The horned Moon, with one bright star
Within the nether tip."

*Fourth Adolfo Stahl Lecture.

are classic; and we have all in our childhood recited or at least read *The Burial of Sir John Moore* with the line

"By the struggling moonbeam's misty light."

Some critic was unkind enough to look up the almanac and he found "that the Moon was new on the 16th of January, 1809, at one o'clock in the morning of the day of the battle of Corunna." The Moon was therefore invisible on the following day and since the burial took place on the night after the battle it was, in any event, below the horizon.

It would be easy to cite many other passages in which similar errors occur. Nor are these mistakes confined to writers in our own language. William Lyon Phelps, for instance, in his *Essays on Modern Novelists*, says that "the Moon, in German fiction, is not astronomical, but decorative. I have read some stories in which it seems to rise on almost every page and is invariably full. Even Herr Sudermann places in *Es War* a young crescent Moon in the eastern sky!"

Our modern civilization and our educational system are to a large extent responsible for this general ignorance of the apparent motions of the most familiar of all the objects in the night sky. Astronomy, in our country at least, is seldom taught in the schools and generally only as an elective in our colleges, and boys and girls can pass thru all the grades to a university degree without acquiring the slightest information about the Sun, the Moon, the planets or the stars. And our crowded hurrying life with its insistent and ever growing demands upon our time affords ever less leisure for quiet observation and thought, and city lights too often hide from us the lights in the sky. That is why I am devoting the first part of this lecture to a simple account of the Moon as we see it in the sky.

It requires no observatory equipment—not even the smallest telescope—to gain a knowledge of the apparent motions of the Moon in the sky. It is only necessary to watch it with seeing eyes, as the ancients did, thousands of years before the telescope was invented. Any intelligent boy or girl can repeat these observations and verify what I am going to say, and I hope that many of you who hear me tonight will do so. When it comes to the real motion of the Moon the story is very different. To trace this motion in detail, to analyze it, and explain it on the Newtonian theory of gravitation forms one of the most intricate and diffi-

cult problems of mathematical astronomy. The trouble is that so many factors enter. If the Moon moved simply under the mutual attraction between it and the Earth, the problem would be the comparatively simple one known as the two-body problem. But the Sun's attraction is a powerful disturbing—or, in technical terms, perturbing—force; *Venus* exercises a strong attraction; the other planets, in smaller degree, enter, each with a force determined by its mass and distance; even the fact that the Earth is not a sphere, but bulges at the equator, is a factor by no means to be neglected. The Moon, therefore, does not move in a simple elliptic orbit, but in a very irregular curve, following the line of the ellipse only in a general way, and it is so near the Earth, relatively speaking, that every departure from simple elliptic motion is detected in our observations. To account for the observed motion under the law of gravitation, taking all the disturbing factors into consideration, is a problem that has exercised the highest powers of great mathematicians from Newton's time to the present day. We may well be proud of the fact that three American astronomers — the late Simon Newcomb, the late George William Hill, and Professor Ernest W. Brown of Yale University—have taken distinguished parts in the solution of this great problem. Professor Brown's lunar tables, now being printed, are the most accurate ever constructed.

Returning, after this digression, to the Moon's apparent motion, the diurnal motion due to the rotation of the Earth on its axis is the first to be noticed. We see the Moon rise above the eastern horizon, circle the sky towards the west, and set below the western horizon. The points of rising and setting are not always the same nor does the Moon cross the meridian always at the same altitude, and the times of rising change from day to day. The observer will quickly learn to associate the times of rising and setting with the Moon's age and its phases. For a day or two at new Moon time he will not see it rise or set at all. Then, if he is sharp-eyed and the air is very clear, he will see it rise shortly after sunrise, a slender crescent. As the crescent grows from day to day, the time of rising becomes later and later until, when the crescent has rounded thru the half Moon and gibbous phases to full Moom, it rises in the east about the time the Sun is setting in the west. As it wanes again, first to the half Moon phase, and then, in the last quarter of the month, to an ever nar-

rower crescent, the time of rising grows ever later until we see it rise for the last time in the month just before sunrise.

Of course this retardation in the time of its rising is due to the fact that the Moon is really moving about the Earth from west to east. Watch it for a few hours in any clear moonlight evening and you will find that in an hour's time it moves eastward among the stars about the distance represented by its own apparent diameter. Continue your observations and in due time you will learn that it requires approximately $27\frac{1}{3}$ days to return to its original position among the stars so far as its eastward motion is concerned; but now it may be a little farther north or a little farther south than it was a month earlier. This is a little more than two days less than the time it requires to pass from new Moon back again to new Moon, and the reason is obvious when we recall the fact that because of the Earth's motion in its orbit the Sun also seems to move eastward among the stars. In a month's time it travels over nearly $\frac{1}{12}$ of its orbit, and the Moon must catch up with it before it can again reach the new Moon phase. It is also clear that the phases must in some way be related to the change in the Moon's position with respect to the Sun, for full Moon always comes when the Sun and Moon are on opposite sides of the Earth, new Moon when they are nearly in line on the same side.

Note the Moon's size and you will find that it is always about the same but that it does vary slightly. At one time in the month it is a little larger than the average, at another a little smaller. But in making this observation be careful to watch the Moon when it is about the same distance from the horizon, for it always looks larger when near the horizon than when it is higher in the sky. This is an illusion, for the Moon is then really farther away and actually its disk is a little smaller.

After careful and long continued observations of this kind the ancients were able to conclude in the first place that the Moon's orbit about the Earth—its apparent path among the stars—makes an angle of about $5°$ with the ecliptic. This explains why the Moon sometimes rises north of the east point, and sometimes south of it, for the ecliptic itself makes an angle of $23\frac{1}{2}°$ with the plane of the Earth's equator, and the Sun is south of the equator from the autumnal equinox, about September 21, to the vernal equinox, about March 21, and then north of it thru the next six

months. Let us note just here that since the Moon at full is always opposite to the Sun, the full Moon must be north of the equator during our winter months, when the Sun is south of it, and south of the equator during the summer months. The full Moon therefore "rides high" in the sky and gives us the most light in the winter when we have the least sunlight, and rides low in the sky in the summer. In our latitudes this is not a matter of great consequence, but if we were at the North or at the South Pole, it would be pleasant, at least, to have the Moon above the horizon continuously for the 14 days from the first quarter thru full Moon to the last quarter every month during the long polar night.

Next, the ancients learned that the Moon's distance from the Earth varies by a slight amount corresponding to the slight variation in its apparent diameter and that this variation progresses in a regular manner, completing the cycle of its changes in the period of a month. This we now know is due to the fact that its orbit is not an exact circle but is flattened a little into the form of an ellipse. Of course they also learned that the Moon does not shine by its own light but only by reflected sunlight. This led to an understanding of the phases of the Moon.

A careful study of some of the prominent markings on the Moon's surface will soon convince anyone that they always remain in approximately the same position with respect to the limb; that is, that the Moon always turns the same face toward the Earth. This means that the Moon must turn once on its axis—make one complete rotation—each month. That is a puzzling statement to many people when it is heard for the first time but it is easy to show that it is true, and that in no other way could the Moon keep the same face turned toward us. Try walking around a table placed near the center of a room always facing the table as you walk and see what happens! You will find, that in making the round, you have faced each wall of the room in succession; that is, you have yourself turned once completely round during your walk.

I said just now that the Moon always keeps the same face turned toward the Earth. This is true in a general way but the statement is not quite exact. The Moon's equator is inclined 6½° to the plane of its orbit, consequently at one time in each month its north pole is tipped 6½° toward us, and two weeks later its south

pole is similarly tipped. Therefore we see a little beyond first one pole and then the other each month. This slight variation we call the libration in latitude. Further, since the Moon's orbit is an ellipse its motion in its orbit will be variable, being slower when it is farthest from the Earth and faster when it is nearest; but its motion of rotation on its axis is perfectly uniform. This produces what we call the libration in longitude and permits us to "see alternately a few degrees around the eastern and western edge of the lunar globe." Finally, the Moon when it rises and when it sets is practically on a plane passing thru the center of the Earth while we are about 4,000 miles above that plane; therefore we look a little past the western limb of the Moon as it rises and a little past its eastern limb as it sets. The net result is that 41/100 of the Moon is always visible, 41/100 is never visible, and the remaining 18/100, along the limbs, is sometimes visible and sometimes not.

The Moon is so near the Earth that its distance can be measured with very great accuracy. One method of doing this is, in principle, precisely like that which a surveyor employs to determine the distance to an inaccessible object. The surveyor measures off a base line of suitable length from both ends of which the object is visible. At each end he then measures the angle included between the other end of the line and the object. This gives him a triangle in which he knows the size of three independent parts—one side and two angles—and from these he can readily compute the other parts. In the case of the Moon we measure its distance from the zenith at two stations having nearly the same longitude but widely separated in latitude, the observatories at Greenwich, England, and at the Cape of Good Hope, South Africa, for example. Knowing the latitudes of our stations we have for our base line the length of the line between them drawn thru the Earth's crust, and the measures of the Moon's zenith distance supply our angles. Then we calculate the distance from each observatory to the Moon and from these values the distance to the Moon from the Earth's center. The mean value has been found to be 238,862 miles; but it is easier to remember the value 240,000 miles, a round number that is sufficiently exact for any one except the specialist. Having the Moon's distance, our measures of its apparent angular diameter can be converted into

miles. This leads to the figures 2160 miles, a little more than one-fourth the diameter of the Earth.

Several of the satellites of *Jupiter* and of *Saturn* are fully as large as or even larger than our Moon, but the planets themselves are so much larger than the Earth that the contrast between planet and satellite is very much greater. Our Moon, in fact, ought really to be called the Earth's companion rather than its satellite. Viewed from *Venus* or from *Mars* it would easily be seen without the telescope, forming with the Earth a beautiful double star.

It is its nearness to us, however, rather than its size that makes the Moon the only body except the Sun which exercises a direct influence upon our lives here on the Earth. I am speaking now from the strictly utilitarian point of view. Planets and stars could be blotted out and in one sense our lives would go on without the slightest inconvenience, tho our intellectual and spiritual loss would be immeasurable. But let the Moon be annihilated! Immediately the effect would be felt in every shipping port in the world. The ships in dock could not get out; the ships outside could not get in; and the maritime commerce of the world would be thrown into dire confusion, for the Moon is the principal factor in producing the tides. The Sun also raises tides on the Earth but its effect is only half that of the Moon.

We cannot enter now upon the story of the tides; that would make a lecture in itself. But I want to take up one point very briefly. If the Moon raises tides upon the Earth, then the Earth must likewise exercise a tidal strain upon the Moon and because the Earth's mass is so much the greater of the two, this strain must be about 20 times that exerted by the Moon upon the Earth. We think of the tides as a phenomenon connected with the ocean, but a moment's reflection will make it clear that the pull of the Moon is just as strong upon the solid crust of the continents. The waters of the ocean are freer to move, that is all. Now it can be shown that when a body rotates upon its axis in the same direction as its motion in its orbit, and the rotation time is shorter than the revolution period such a tidal force acts as a brake to slow up the rotational motion until the two periods are equal. It is thought by most astronomers that the Moon originally rotated much faster than it does now and that the cumulative effect of the Earth's tidal action upon it thru the ages is responsi-

ble for the fact that now its rotation time equals its revolution period.

The Moon has been credited with many other influences upon us, malign as well as benevolent. Our words *lunacy* and *lunatic* preserve the idea once universally held that moonlight can affect the minds of men; countless wise sayings embalm the belief that the Moon affects the weather; and others, the belief that the planting of various crops, to result in fruitful harvests, must be timed to the right phase of the Moon. These are all superstitions worth as much or as little as Tom Sawyer's method of curing warts. Not one of them has a basis of fact, but they cling tenaciously to men's minds and still influence the actions of some. In a certain region of the San Joaquin Valley, for instance, no farmer, even today, plants his cabbages without first consulting an almanac!

Consider the Moon and the weather. We are told that changes in the Moon's phases—at the quarters, full and new—bring changes in the weather. Now, in the first place, the Moon could only affect the weather by variations in the amount of heat it radiates to us. There is a variation in this respect, it is true, for not only is the illuminated surface at the quarter phase only half that of the full Moon but, because of the rough surface of our satellite, this surface sends far less than half—only 1/9th or 1/10th—as much light and heat as the full Moon. But even the full Moon sends so little that it can have no appreciable effect, in fact it sends only 1/465,000th as much as the Sun. Taking the phases into account, it is found that in *13 seconds* we receive as much light and heat from the Sun as we do from the Moon in a whole year! Evidently, then the Moon's heat is quite unimportant to us; a light cloud passing in front of the Sun deprives us of more heat than the Moon ever sends us. In the second place, storm centers travel across the Earth, generally from west to east in our latitudes, and can often be traced clear across a continent, or even half way round the globe in the course of a week or two. If the storm begins with a change in the Moon at one station, it clearly will not begin with such a change at another station some hundreds of miles east or west of the first one. Finally, records kept at many stations for long periods of time—a hundred years in some instances—show no relation whatever between Moon change and weather change, tho chance coincidences are of course frequently found.

Now let us look at the Moon itself as it is revealed to us by the telescope. Our first surprise is to find the surface so extremely broken and rugged; the next is that we can see the details of all the features so clearly. Visitors to the Lick Observatory often ask how near the great telescope brings the Moon to us. This, of course, depends upon the magnifying power we use. With a power of 1000, which is as great as can be used to advantage under ordinary conditions in studying the surface of a planet or of the Moon, it is, in effect, brought within about 240 miles of the Earth's surface. But this does not give quite a fair idea of the distinctness with which we see the lunar surface details because when we view an object like a mountain 240 miles distant on the Earth we are seeing it thru a much denser layer of our atmosphere. On a clear winter's day at Mount Hamilton, for example, we can see the Sierras stretching from the far northeast to the far southeast and can readily make out some of the prominent landmarks about the Yosemite Valley 180 miles due east of us without the aid of glasses. But we cannot see them as well defined as we do the Moon's features thru our telescopes. Objects on the Moon having a diameter of 1,000 feet are easily seen and those with half that diameter would hardly escape detection. Smaller inequalities of the surface, or an ordinary house, a single tree, or animal or plant would be invisible. Rugged as the Moon looks to us therefore, its actual surface is probably rougher still.

On that side of the Moon which is visible to us, there are no less than ten mountain ranges of considerable extent, numerous isolated peaks, some 10,000 cracks or "rills" and more than 30,000 "craters" which have been mapped and, for the most part, named. There are also the large dark areas which from Galileo's time have been known as "maria" or seas, tho we have long been aware that they are dry. The system of nomenclature dates back to Riccioli, who, in 1651, published a lunar map on which several hundred mountains and craters were named for distinguished astronomers and mathematicians. The names *Alps* and *Appennines* and a few others date back still farther—to 1645, when Hevelius constructed the first satisfactory map of the Moon.*

The Moon, then is a world, as someone has said, which has no weather and where nothing ever happens.

*At this point in the spoken lecture, a detailed account of many of the lunar landscape features was given, with the aid of lantern slides, and reasons were given for our belief that the Moon has no appreciable atmosphere.

The question of the origin of the various lunar surface features is one on which astronomers are still in doubt. It is not difficult to conceive of the formation of the mountain ranges, lofty as some of them are, and of the valleys or canyons and of the smaller craters, at least, by forces similar to those which have produced corresponding features upon our Earth, especially when we consider the fact that, because of the Moon's smaller mass, a given force acting against gravity there would be about six times as effective as here. But the bright lines or rays running out from some of the craters are unlike anything familiar to us on the Earth's surface, and there are great difficulties in the way of accounting for the craters themselves.

By many astronomers they have been ascribed to volcanic origin as their name indicates. The chief objections to this theory are, (1) that there are so many craters and that they are often so very large—60 or even 100 or more miles in diameter; (2) that the material in the surrounding walls and peaks is not sufficient to fill the crater bowls; and (3) that there are few or no evidences of lava flows. Other astronomers believe that the craters originated in impacts from falling meteors. Here again, the objections are of great force: (1) the bombardment must have been a terrific one to form so many and such large craters and since the Earth and Moon revolve in the same general path about the Sun, and the Earth is so much the larger of the two, craters should be correspondingly more numerous and as large upon the Earth. As a matter of fact only one crater on the Earth—the celebrated "crater mound" in Arizona—is known that was probably formed by a falling meteorite. Advocates of this theory, however, point out that the lunar craters were undoubtedly formed many millions of years ago and that erosion on the Earth has probably erased all traces of the craters formed here at that time. Granting this, it would seem that there should be evidences of their former existence in the rock strata examined by geologists and so far as I am aware these have not been found. (2) An even greater objection to the theory is that, to form the lunar craters we see, the meteors must all have fallen vertically upon the Moon's surface, and it can readily be shown that this would be possible, if at all, in only a very small percentage of cases. Nearly all collisions must have been with meteors moving at acute angles with the surface at the time of contact and evidences of this fact should be visible for there is no "weathering" on the Moon.

On either theory it is difficult to account for the bright rays around such craters as Tycho and Copernicus, for they run in nearly straight lines over craters, cones and seas alike, often for hundreds of miles; and at no phase angle do they cast shadows. They can therefore not be elevations above the surrounding surface. Some regard them as cracks filled up later with matter of a light tint, as quartz fills rock veins in our own state.

I have stated the objections to the theories rather than the arguments in their favor because the objections must in some way be removed before either theory can be accepted as satisfactory. Some recent work by Professor R. W. Wood, however, may be referred to here which to some extent seems to favor the theory of origin by volcanic or similar explosive forces. He has photographed the Moon in light of different wave lengths, first in yellow light, then in violet and finally in ultraviolet light, and the three sets of photographs show some marked differences in appearance. For example, a large dark patch just above the crater Aristarchus appears on the ultraviolet picture, which is practically invisible in the yellow one and only faintly visible in the violet one. Professor Wood took two specimens of volcanic tufa of about the same color, one of which photographed light and the other dark in rays of ultraviolet light. Placing a small chip from the dark specimen upon the light one he secured effects exactly reproducing those shown by the Aristarchus spot. Analysis then showed that the dark chip contained iron and traces of sulphur. Experimental photographs of many rock specimens having iron stains failed to give these effects, but by taking the specimen of tufa which had photographed light in the ultraviolet picture and forming on a spot on its center a very thin deposit of sulphur—so thin as to be invisible to the eye—he obtained photographs showing the spot quite black in the ultraviolet, gray in the violet and invisible in the yellow. This makes it appear probable that there is a deposit of sulphur near Aristarchus on the Moon. More extended work along this line is needed, however, before any theory of crater formation can be based upon it.

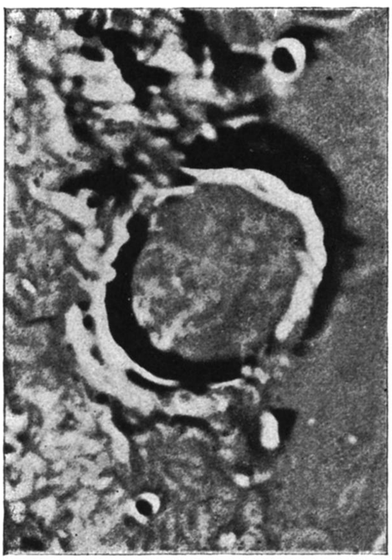
I have said that the Moon is a world where nothing ever happens. Some astronomers would take exceptions to this, and it is perhaps well to remind ourselves that a universal affirmative (or negative) is a dangerous form of statement. It is quite conceivable, for instance, that a large meteorite *might* strike the Moon at some time

and that we *might* be able to detect the effect. Again the extremes of temperature to which the surface is subjected may result in some cracking, tho it is doubtful whether this could proceed on a scale large enough to become visible. Physical changes, particularly in connection with the small crater Linné, have been reported by some expert observers; but others say that "no eye has ever seen a physical change in the plastic features of the Moon's surface."

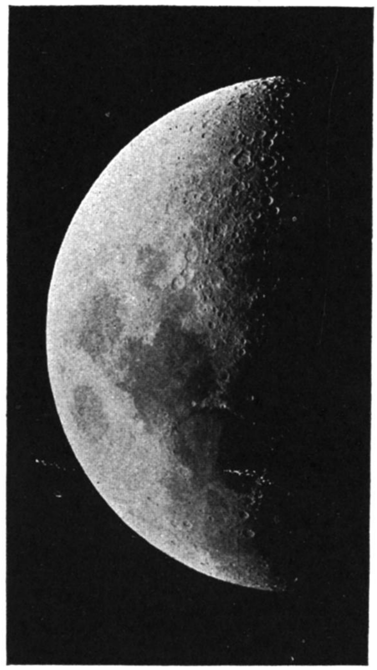
Definite and very positive statements are made by some competent observers that slight color changes take place in the course of each month in the neighborhood of certain of the craters, and some have ascribed these to the issuing of vapors from the cones. Because there is no atmosphere, these vapors would be immediately deposited as snow or hoar frost in the lunar night and evaporated during the lunar day, and would thus explain the observed changes in appearance. More data are necessary before any certain conclusion can be reached.

This is true even of the nature of the general surface of the Moon. Most authorities agree that the surface is a dry barren desert of rock and debris covered with a deposit of meteoric dust such as exists in our own atmosphere and is found on the snows of the polar regions and even on the bottom of the ocean; but there are others who think it is covered with a thick deposit of ice! The Moon may be a dead world, but it clear that it will long continue to be an interesting body to study.

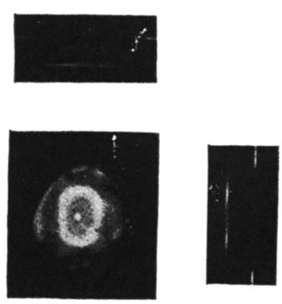
February, 1917.



The Lunar Crater Archimedes



The Moon at First Quarter



Planetary Nebula N. G. C. 7662 and Spectrum
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